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# Assessing the Influence of Flow Variability on Irrigated Agriculture in the Central Gharb Plain, Morocco

Driss El Karfa[1], Jamal Al Karkouri[1], Mouhcine Batchi[1] and Hommane Boudine[2]

[1]Laboratory of Territories, Environment and Development, Faculty of Human and Social Sciences, Ibn Tofail University, Kenitra 14000, Morocco: [2] Geosciences Laboratory, Faculty of Sciences, Ibn Tofail University,14000, Kénitra, Morocco.
*Corresponding author's e-mail: driss.elkarfa@uit.ac.ma

The lower main watercourse of the Sebou Basin in Mechra-Bel-Ksiri is experiencing adverse effects attributed to climate change, notably drought and rising temperatures. In this study, we evaluated the impact of these changes on the irrigation zone using a comprehensive methodology involving break, trend, and low-water analyses. Our assessment, incorporating Land Use and Land Cover Change (LULCC) considerations, reveals detrimental effects on the expansion of irrigated agriculture along the Sebou wadi and its Baht tributary. Consequently, farmers are compelled to tap into underground water sources to fulfill irrigation needs for their farms. This research sheds light on the pressing challenges posed by climate change in the region and the consequent adjustments farmers are forced to make in their water sourcing practices.
**Keywords**: Flow variability; break; trend; low water; land use land cover.

## INTRODUCTION

Food security is one of the major challenges facing the world's population, regarding both availability (production) and distribution. That's why the United Nations (2018) has emphasized food security as one of the 17 Sustainable Development Goals (SDGs) (Jasman *et al.*, 2023). Water resources are pivotal in guaranteeing food security for countries classified in the arid and semi-arid bioclimatic stages, where irrigation is essential. Recent climate changes show that air temperatures have increased at several levels (Ji *et al.*, 2014; IPCC, 2022; Boško *et al.*, 2018; Gerard *et al.*, 2013).
This rise in temperature increases the actual evaporation from water surfaces and plants, which in turn increases the deficit in water resources. Climate forecasts based on the Trewartha climate classification (TWCC) show an increase in global temperature in C° and a change in the amount of precipitation in mm (Valjarević *et al.*, 2022).
This warming is accompanied by variations in the hydrological cycle, due to changes in the intensity, frequency, and duration of precipitation, as well as in the temporal and spatial distribution of water. These climatic variations will have adverse effects on river flows in humid, semi-humid, semi-arid, and arid environments such as the Mediterranean basin, where the onset of these rivers is a naval and pluvial oceanic regime, with high water in the cold season and low water in the warm season. Evaporation plays a major role here, as rainfall in the low-water season is often equal to or even greater than in the high-water season.
The inter-annual irregularity of the regime is considerable, and the period of maximum high water shifts considerably from one year to the next, depending on the whims of the rains. In Mediterranean climates, the regime has a more pronounced minimum in August and September, with the maximum around November, December, and January (Remènieras, 1976).
Morocco is one of the Mediterranean countries whose climate is characterized by frequent periods of drought (Damnati, 2006), which hurts the river flow regime, bearing in mind that Morocco lies between 25° and 40° north of the equator, where drought has become a cyclical phenomenon due to the Azores anticyclone (Pédlaborde, 1982). This situation obliged Morocco to initiate agrarian reform in several of the country's basins, including the Sebou basin, which underwent water management in partnership with the World Bank (François-Troin, 1996).
This development is based on the Oued Sebou and its tributaries through the construction of dams in front of the basin to guarantee a sustainable water supply to the plots of land developed at the bottom of the basin in the Gharb plain, which is one of the areas developed in the overall context of

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the agricultural reform affecting this area, taking advantage of the natural wealth of the plain, namely the intensity of the wadi networks, the flat land and the fertility of the soil. This plain has been canalized for irrigation, subdivided by slice and sector, but it does not cover the entire Gharb territory.

We chose the Mechra-Bel-Ksir hydrometric station, because it is the only station in the plain containing sufficient data for this study, in addition, it has the same topographical characteristics of the study area. On the central Gharb plain, the nature of the soil has made it possible to grow a huge range of crops in the dry season, including rice, maize, and some types of vegetables. These crops have been detected by Land use and land cover change (LULCC). Lately, however, we've noticed that there are problems with irrigation water for summer crops. So there are several issues linked to the level of water flow and irrigated area at this stage.

## MATERIALS AND METHODS

- ***The study area*:** The study area belongs to the Gharb plain, which is a homogeneous space but is surrounded by significant elevations, making the plain a collector of water from the Sebou basin downstream. Regarding the hydro-morphological organization of the plain, the Sebou levee is the guiding element. It stands at 25 m at the confluence with Ouergha, 17 m at Mechra-Bel-Ksiri, 13 m at Souk-et-Tleta, 9 m at Sidi-Allal-Tazi and 3 m at Kenitra. The study area is characterized by its low altitudes, as shown in Figure 1 since the central plain conforms to the central Merja area between the left bank of Oued Sebou and the right bank of its tributary Beht ( Le Coz, 1964).

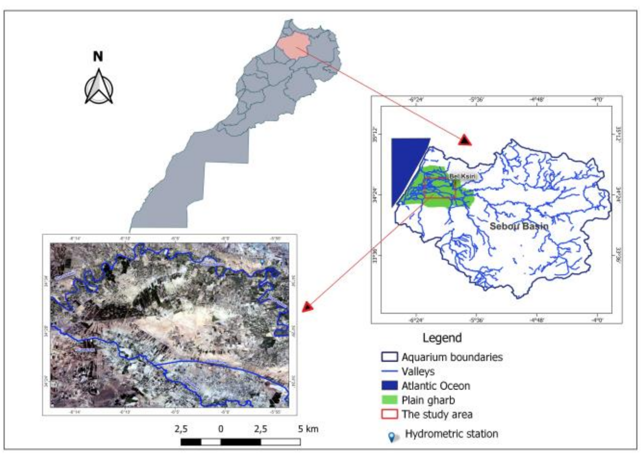


**Figure 1. Location of the study area**
**Source:** Sebou Basin Agency, Fez

***Data*:** This article is based on a bibliography related to water resources in particular and climate change in general, to detect changes affecting flow variability in the Mechra-Bek-Ksiri station, which is the most suitable for this study as it is the only hydrometric station located in the central plain and has almost the same altitudes as the study area. The Sebou basin agency has provided us with statistical data on annual modulus flow from 1967 to 2012, and daily mean flow from 1975 to 2020.

***Methods*:** We used several statistical approaches, namely the break test, the trend test, and the calculation of low flow rates, these approaches helped us to detect the flow state in the Mechra-Bel-Ksiri hydrometric station.

To study the stationarity or otherwise of the flow at Machraa Bel Ksiri, we opted for three different methods: The Pettitt test (PETTITT, 1979), Buishand's U statistic (BUISHAND, 1984), and Lee and Heghinian's Bayesian procedure (Lee and Sylva, 1977). A non-stationary flow series exhibits a break which results in a change in the mean. When a break is detected in a flow series, we are interested in calculating the variation of the mean on either side of this break, expressed by the following formula (Ardoin-Bardin, 2004): D = (Xj - Xj), where X j represents the series mean over the period after the break and Xi the series mean over the period before the break. Break detection is performed using Khronostat software (open-source software proposed by the Hydrosciences Department - University of Montpellier).

The non-parametric Mann-Kendall or MK test (Mann, 1945; KENDALL, 1975) is adopted to determine the presence or absence of a linear trend in the study series analyzed (POHLERT, 2018). The null hypothesis H0 (no trend) is rejected when the significance level or eigenvalue (p-value) exceeds 5%. When H0 is accepted. The robustness of the test was validated by several comparison tests (YUE and Chun, 2004; Lubes-Niel *et al.,* 1998). Trend detection was performed using XLAST software (trial version at https://www. xlstat.com/f).

***Calculation of low-water flows***: Minimum flow of a river calculated over a given period during low-water periods. Thus, for a given year, we speak of daily low-water flow, low-water flow for consecutive days, and monthly low-water flow – the average of daily flows for the low-water month (QMNA). (https://www.eaufrance.fr: consult on 10/19/2023). Absolute low flow (or absolute minimum flow) does not require the elaboration of a curve of classified flows, but is based on all available average daily flows: it represents the lowest known flow of a river (Remènieras, 1976).

Low-flow analysis is often based on a series of annual flows (one value extracted per year). However, not all of these flows represent an extreme hydrological situation, particularly in very wet years.

To monitor the evolution of irrigated crops, we studied them over three different years; 1996, 2006, and 2022 (Table 1). To carry out this assessment, we used Landsat satellite images

with a spectral resolution of 30m, to map, and compare between irrigated areas and detect the impact of flow variability on the extensions of irrigated crops. The images downloaded are from July for all three years, allowing us to differentiate between crops that are well advanced in their summer vegetative cycle.

**Table 1. Informations détaillées sur les images Landsat utilisées dans la recherche.**

| Year | Satellite | Sensor | Reso-lution | Acquisition date | Source |
|---|---|---|---|---|---|
| 1996 | Landsat 5 | TM | 30 m | 18/07/1996 | https://earthexplorer.usgs.gov |
| 2006 | Landsat 7 | ETM | 30 m | 30/07/2006 | https://earthexplorer.usgs.gov |
| 2022 | Landsat 8 | OLI/TIRS | 30 m | 26/07/2022 | https://earthexplorer.usgs.gov |

This tool transforms DNs (digital counts) into radiance or reflectance (Benhadj, 2008).

In principle, images are converted to radiance values using the following equation:

$(\lambda) = A(\lambda) * CN + B(\lambda)$

L(λ): Apparent luminance (Radiance)

λ: wavelength

A(λ): Gain

B(λ): Offset

Landsat-8/OLI and Terra/ASTER have undergone this radiometric calibration to ensure correct images. This is a correction to eliminate atmospheric effects such as scattering and absorption. There are several models for quantifying the atmospheric contribution to the luminance of each pixel in the scene. For Landsat-8/OLI, the method used is Dark Object Subtraction (DOS). The DOS method is based on the numerical counts of black objects in the image with a reflectance other than 0. These values are attributed to atmospheric effects.

Concerning Classification, which consists of categorizing the elements of a multi-spectral and multi-temporal image, using the correspondence between the radiometric values of the pixels in this image and a set of thematic classes, whether known or not.

Classification methods can be divided into two broad categories:

- Unsupervised classification: NSC methods propose groupings based on the structure of the pixels present in the image, with no a priori information on the areas to be identified. They consist in forming spectral classes based on numerical information and pixel statistics (Masse, 2013)
- Supervised classification: For supervised methods, we need to select fairly homogeneous samples of the image, representative of different types of surfaces or classes. These are generally selected based on observations made in the field, by choosing plots representative of the different elements to be classified. Then, with the help of algorithms, the computer determines the digital signature of each training class and can recognize the spectral classes represented therein.

Concerning NDVI: Normalized Difference vegetation index; is a simple graphical indicator that can be used to analyze remote sensing measurements, often from a space platform, by assessing whether or not the observed target contains living green vegetation.

A high NDVI value indicates healthy vegetation, which absorbs most of the red and reflects much more of the near-infrared, and vice versa (Fig. 2).

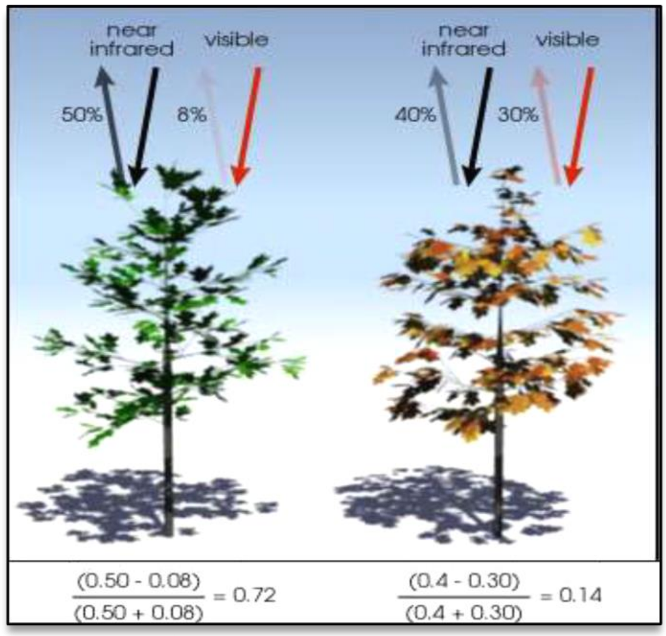


**Figure 2. NDVI variation according to plant health, (a): healthy plant, (b): stressed plant (visibleearth.nasa.gov)**

ow to calculate the NDVI index:

We use the reflectance of the red(R) and near-infrared (PIR) channels measured in the visible band by satellite-borne sensors.

$$NDVI = (PIR - R) / (PIR + R)$$

## RESULTS

***Variability of modulus flow at the Mechra-Bel-Ksiri hydrometric station*:** Modulus flow is extracted from Oued Sebou at the Mechra-Bel-Ksiri station, where the main course of the Sebou basin becomes slow because of the low altitudes. Figure 3 shows us that the annual flow rate is decreasing. Still, the curve does not have the same shape, which means that the regime of this watercourse is irregular because the average interannual flow rate that we observe (103 $m^3/s$) shows that there are fluctuations recorded within the series

studied, which disrupts the regular supply to irrigated circles such as the irrigation sectors in the study area. However, this analysis is insufficient. It is therefore essential to perform trend and breakpoint tests on the statistical series under study.

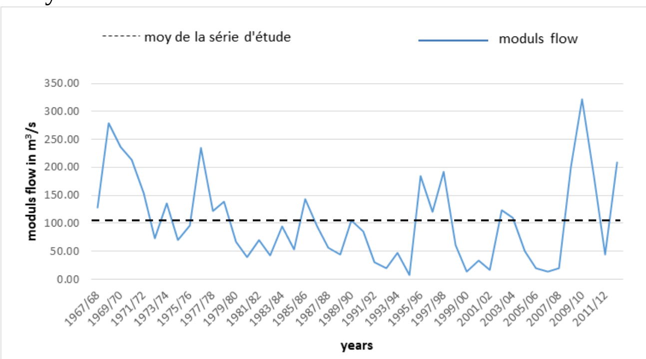


**Figure 3. Modulus flow from 1967-1968 to 2011-212 at Bel Ksiri station.**

**Source:** Raw data, Sebou basin agency, Fez

***Detection of flow breakage*:** The results of the various tests are similar and mark the beginning of 1779 as a year of change in the Oud Sebou watercourse (Table 2).

**Table 2. Break detection test in the interannual flow series at Bel Ksiri.**

| | Rank correlation test | Pettitt test | Buishand Test | Lee and Heghinian test | Segmentation de Hubert |
|---|---|---|---|---|---|
| Module flow | No break | 1979 | No break | 1979 | 1979 |

The change affecting the annual flow was detected in 1979 according to the tests shown in the table above. So the year 1979 was marked as a year of rupture in the flow regime in the hydrometric station at the bottom of Oued Sebou.

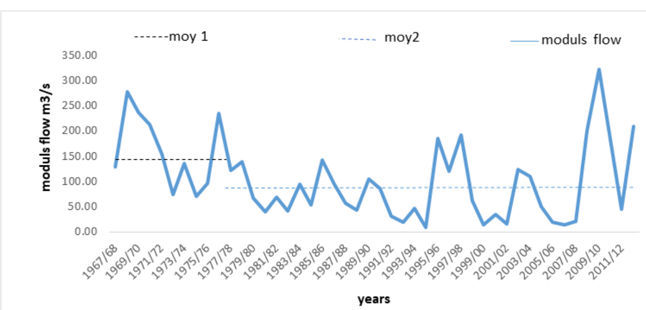


**Figure 4. The graph obtained by the tests of Pettitt, Lee, and Heghinian test and Hubert segmentation, applied to the Mecha-Bel-Ksiri series (1967/1968 - 2011/2012) where moy1 and moy2: mean interannual discharge before and after the detected break.**

The results of the different tests are similar and mark a significant break in the flow of Oued Sebou at Mechra-Bel-Ksiri in 1979, as shown in Figure 4. This change experienced a regression on average in the flow because we rerecorded the previous average which was 148m$^3$/S and the next average which is 86 m$^3$/S, so the deficit is -62m$^3$/s. Figure 3 displays the change in flow in the central Gharb plain.

***Application of the M.K. test to the study series*:** Application of the Mann-Kendall test revealed that the trend in the flow series at the study station is statistically significant at the (5%) threshold (Table 3).

**Table 3. Results of the Mann-Kendall test applied to the modulus flow rate.**

| | Test de Mann Kendall = 0.05 | Tendance |
|---|---|---|
| **The annual flow** | 0.032 | + Significative |

The Mann-Kendall test shows a downward trend in flow at the (95%) confidence level at the Mechra-Bel-Ksiri hydrometric station.

***Study of low-water flow in the central plain*:** Low water levels are of particular economic interest, as they condition irrigation. This study adopts three types of low water: monthly low water flow, average daily low water flow (QMNA), annual low water flow, and absolute low water flow.

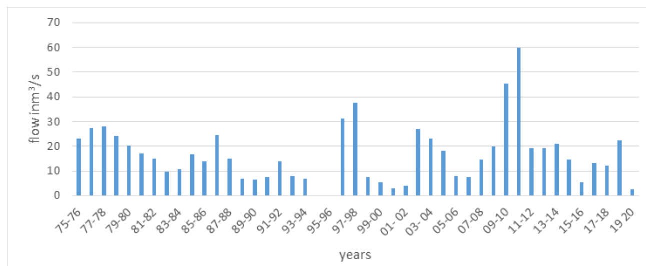


**Figure 5. Monthly low-flow rate, an average of daily low-flow rates for the month, in Mechra-Bel-Ksiri hydrometric station (QMNA)**

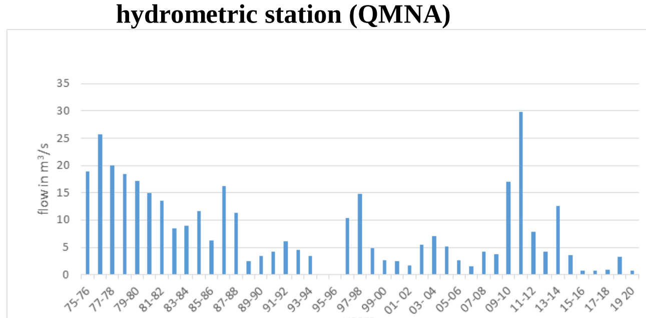


**Figure 6. Annual low-water flows in Mechra-Bel-Ksiri hydrometric station**

The absolute low flow is 0.

According to the three types of low water, we note that the minimum minimorum 0 m3 /s in the 1994/1995 season from 08/08/1995 to 22/08/1995 and in the 1995/1996 season from 09/23/1995 to 11/13/1995 is very exceptional. The lowest low-water levels observed were recorded in August and

September, and the minima recorded since the 1988/1989 season, at around 2 $m^3/S$, appear to have been affected by pumping for citrus and especially rice.

***Expansion of irrigated farming*:** To monitor the extension of irrigated areas in the central Gharb plain, we adopted satellite imagery that enabled us to compare three years: 1996, 2006, and 2022 in July, considering that the study area has no vegetation cover as everything is cultivated.

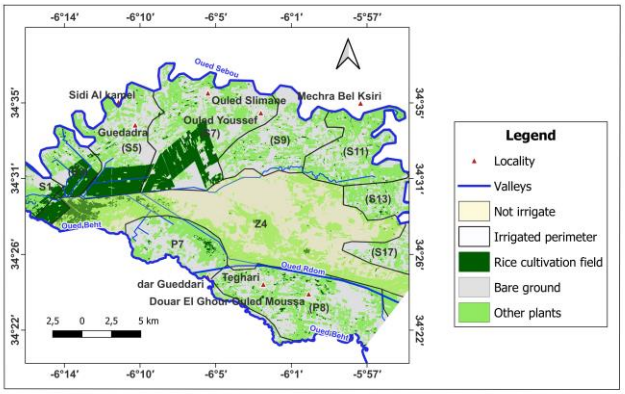


**Figure 7. Land Use Land Cover Analysis 1996, of the Study Area.**

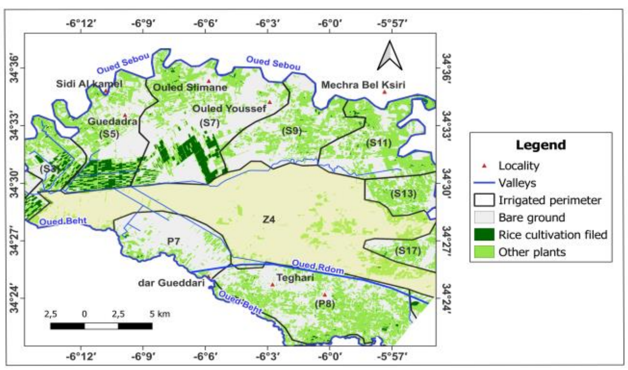


**Figure 8. Land Use Land Cover Analysis 2006, of the Study Area.**

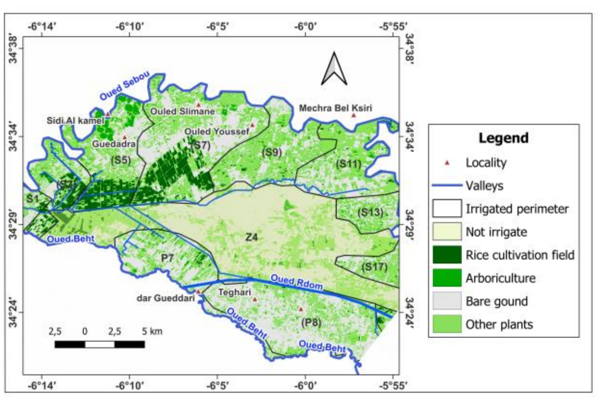


**Figure 9. Land Use Land Cover Analysis 2022, of the Study Area.**

The study area is classified in the semi-arid bioclimatic stage, which means that water constitutes a pivotal factor in agricultural production. Temporal monitoring of irrigated areas in July where crops rest entirely on water. As shown in the maps, the year 1996 has a significant irrigated area (35%) compared to 2006 (25%) while the year 2022 (40%), the year 2006 is marked by a worrying regression in irrigated plots, on the other hand in 2022 there was an expansion in irrigated areas.

## DISCUSSION

The study of the impact of variability in the flow of Oued Sebou in the central Gharb plain on irrigated agriculture has justified that the power of this watercourse is regressing, this is detected in the change in the average of the break year in Table 2, and figure 4, as well as through the light trend adopted in this study in table 3. In addition, the flow regression is still apparent in the low-water flow in Figures 5 and 6.

Thus, these three tools (break, trend, and low-flow) adopted in this study have shown that the mainstream in the lower Sebou basin does not have the usual capacity to transfer water for irrigation to plots equipped with state irrigation canals, due to the effects of climate change, namely drought secession and the temperature rise (Karfa *et al.*, 2023) increases the amount of potential evaporation, which hurts the water balance. In this case, spring farming has been based on irrigation, so there is a change affecting the Mediterranean climate, which is characterized by autumn and spring rains.

The choice of July in this study is very important as it reflects the peak time of irrigation use. Secondly, this month is classified as the summer season, when the most profitable crops rely on water: rice, citrus fruit, and vegetables. As these crops are labor-intensive, the Oued Sebou at the bottom of the basin plays a pivotal role in territorial development. However, negative changes affecting the flow regime in the Mechra-Bel-Ksiri hydrometric station are the most representative for this study, thanks to the similarity of the topographical characteristics of the central Gharb plain in general. The effect of these changes on flow was increased from one year to the next.

- In 1996, the irrigation sectors and pumping stations worked well, taking advantage of the Oued Baht watercourse and its tributary R'dm, which explains the extension of irrigated areas in the central plain, even in zones not equipped by state irrigation thanks to these two watercourses.
- In 2006, irrigated areas were reduced due to the negative impact of climate change on rainfall patterns throughout the country, as well as the obsolescence of irrigation canal equipment. As a result, pumping station no. 7 was

shut down and no. 8 became temporary due to silting problems in the El Kansra dam feeding Wadi Baht, despite the canal transporting water from Sebou to Baht to guarantee irrigation water.

- In 2022, the situation became increasingly serious as the years of drought became much more frequent, the inadequate flow capacity of the Bas does Sebou and the drying up of oued Baht and its tributary R'dm, all prompted local players to take advantage of a water-rich underground aquifer at a depth of 85 m and a width of 150 m (Ministry of Public Works, 1994), especially in plots that were not fed directly from oued Sebou. However, the groundwater in the study area and on the Gharb plain comprises renewable reserves (Jean,1996). It is subdivided into two parts: a free surface water table resting on the silt-clay formations of the Quaternary and a deep captive water table resting on the substrate of the Mio-Pliocene Marls belonging to the Plio-Quaternary(Combe, 1975).

***Conclusion*****:** Agrarian reform in the study area is based on the main course of the Sebou basin, but the accentuation of drought years has negatively influenced the capacity of the Sebou's lower flow in the central Gharb plain. This is justified by the method adopted in this study, which is based on tests detecting the break and the trend, then the low-water flow, which means that the irrigation sectors are not regularly supplied with water from the Sebou or its tributary Baht, which does not flow only in wet seasons.

The supply of irrigation water to the study area therefore became a cause for concern in 2006, as shown in Figure 8. Taking into account the need for water in agricultural production, farmers have taken advantage of the richness of the underground water table by digging wells of varying depths to ensure the irrigation supply to their plots.

So we're facing a change in irrigation structures from surface water resources, which are in decline, to groundwater, which is exploited haphazardly. The groundwater is fed by surface water, which comes from rainfall, so this new source of irrigation could be exhausted in the future if massive exploitation is not controlled and rationalized.

Currently, the study area has experienced massive exploitation of groundwater, which requires a new land use strategy and integration of new irrigation techniques based on the potential of the groundwater and the power of the flow of the lower Wadi Sebou.

***Author Contributions*****:** Authors Driss EL KARFA and Author JAMAL Al Karkouri designed the research study. Author MOUHCINE Batchi performed the research. Author HOMMANE Bodine provided help and advice on research Author MOUHCINE Batchi analyzed the data. Authors EL KARFA and BOUDINE wrote the manuscript.

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***Availability of data and material*****:** We declare that the submitted manuscript is our work, which has not been published before and is not currently being considered for publication elsewhere

***Consent to participate:*** All authors participated in this research study.

***Consent for publication*****:** All authors submitted consent to publish this research. article in JGIA

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